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EFFICIENCY OF SELECTING CONTAINER GLASS COMPOSITION

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The analysis of the efficiency of sectional glass-forming machines identifies technological reserves existing in the domestic production of glass containers. Comparative analysis of the physicochemical, technological, and working properties of alternative clear glass compositions for containers glass is performed and demonstrates the advantages of high-calcium compositions. The ways for making use of these advantages to raise the efficiency of container glass production are proposed.

The glass container industry in Russia is expanding capacities for glass bottle production. The introduction of additional production lines and factories has significantly decreased the disparity between offer and demand on this market which is constantly offered new types of products.

The requirements from the side of food and liquor companies imposed on the quality of glass containers have lately substantially grown. Therefore, the deciding factors in producing high-quality products made of clear and tinted glass include the optimization and strict compliance with technological regulations at all process stages, consideration of melting and firing specifics (redox potential of material, batch, and glass melt, chemical composition of glass, effect of impurities and small additives, quality of cullet, etc.). At the same time, the domestic glass container manufacturers not always can solve quality and design problems, therefore, producers of drinks often have to look for foreign bottle suppliers, especially for premium product.

The discrepancy between domestic glass product and the European quality standard to a large extent is due to an imperfect technological process. Contemporary domestic factories use machinery produced by world leaders such as Emhart, Bottero, and BDF, which has high efficiency and product quality potential. The degree of implementation of machinery potential depends on the existing level of the production process.

The most objective information on performance of each production facility compared with other factories can be obtained from the analysis of machinery efficiency provided by the Emhart Company [1]. Participants in the machinery analysis project send production parameters from their factories to the Emhart who processes and compares data and circulates processed results to the customers. Based on the data in [1, 2], we have constructed diagrams of the efficiency of sec-

tional automated machines (Fig. 1). The real parameters of machine performance achieved at different companies in the form of a variance of a number of cuts per minute are indicated on the background of the curve indicating the declared efficiency of automatic machines.

The difference in machine efficiency is quite obvious. Thus, for making bottles weighing 300 g the number of cuts varies from 8 to 11 per min. It is easy to calculate that reaching the top efficiency on a 10-section machine with the double-drop feed is equivalent to an additional production of 8.5 thousand units per day, or over 3 millions units per year. Obviously, there is a lag between the actual performance and the declared output (in this case the parameters of a BDF machine are indicated) when producing items weighing less than 500 g, and the smaller the weight, the more is the lag: for items weighing 100 g (perfume bottle) the difference is equal to 4–6 cuts per min.

The most probable reason for the described facts is the imperfection of the technological process or its individual stages. The current market situation dictates the need to search for rational solutions for each phase of the process,

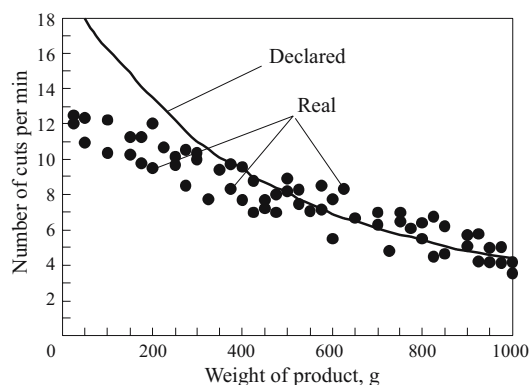


Fig. 1. Efficiency of glass-forming sectional machines.

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TABLE 1

Glass	Weight content, %							
	SiO ₂	Al ₂ O ₃	Σ RO	CaO	MgO	Na ₂ O	SO ₃	Fe ₂ O ₃
BT-1: dolomite lime	72.0	2.5	11.0	6.875 10.5	4.125 0.5	14.0	< 0.5	< 0.1
BT-2: dolomite lime	72.5	1.4	12.5	7.813 12.0	4.687 0.5	13.2	< 0.5	< 0.1

which could raise production efficiently and competitiveness. One of the main factors of the process is a correct choice of the chemical composition of glass that would combine optimal technological and service properties.

The current Russian standard effective since 2004 (GOST R 52022) specifies two compositions of clear container glass: BT-1 and BT-2. It should be noted that the standard does not specify the ratio between CaO and MgO and only prescribes their total content: 11% for glass BT-1 and 12.5% for glass BT-2, leaving to the producer the right of selecting a particular CaO : MgO ratio, ranging from the “dolomite” to the “lime” composition. Therefore, it is necessary to clearly understand the advantages and disadvantages of each variant, as well as methods for making best of the specified advantages in order to raise production efficiency.

We have investigated nominal compositions of clear container glasses with the boundary values of the CaO : MgO ratio: dolomite glasses BT-1D and BT-2D and lime glasses BT-1I and BT-2I (Table 1).

The analysis of estimated values of the physicochemical, technological, and working characteristics (Table 2) demonstrates a clear advantages of low-alkali glass BT-2.

Glasses based on this composition have higher thermal and chemical resistance, which provides for their reliable and efficient service. It should be noted that when correcting a glass composition to raise its chemical resistance, one should not forget the need to provide for its optimum technological (melting and working) characteristics. In our case, despite a decreased content of alkali oxides, the technological temperatures of melting and forming of glasses BT-2 are lower, which makes it possible to decrease energy consumption in glass melting. These glasses are more “short-range”, therefore, they allow for a higher speed of glass-forming automatic machines.

A disadvantage of glass BT-2 compared to glass BT-1 is the increased liquidus temperature. However, taking into account the rather wide safe glass-forming interval ($\Delta t = t_{\text{liq}} - t_{\text{form}}$), which for droplet feed is more than 100°C, the increase in the liquidus temperature by 15–20°C does not present the risk of crystallization. It is noted in [3] that the intensification of glass melting and glass melt preparation and the development of high-speed glass-forming machines have somewhat modified the requirements to glass composition and have practically eliminated the problem of crystallization.

For further comparative analysis we selected two variants of glass BT-2: the lime and dolomite variants.

The temperature dependences of viscosity were calculated using Okhotin's method in the viscosity interval of $10^2 - 10^{12}$ Pa · sec and the MTSh (Mazurin – Tret'yakov – Shvaiko-Shvaikovskaya) method in the interval of $10 - 10^2$ Pa · sec. The equations of Fogel – Fulcher – Tamman (FFT) make it possible to estimate temperature based on characteristic viscosity values or determine viscosity corresponding to any temperature:

BT-2D:

$$\log \eta = -3.27 + \frac{5382.5}{t - 199.7}, \quad t = 199.7 + \frac{5382.5}{\log \eta + 3.27};$$

BT-2I:

$$\log \eta = -2.76 + \frac{4323.5}{t - 274.8}, \quad t = 274.8 + \frac{4323.5}{\log \eta + 2.76},$$

where η is the viscosity and t is the temperature.

TABLE 2

Parameter	Glass			
	BT-1D	BT-1I	BT-2D	BT-2I
<i>Physicochemical properties</i>				
Density, kg/m ³	2480	2491	2487	2499
Modulus, GPa, of:				
elasticity	70.7	71.4	71.0	71.8
shear	28.7	29.1	28.9	29.4
CLTE, 10 ⁻⁷ K ⁻¹	85.0	87.8	83.4	86.0
Water resistance, ml 0.01 N HCl	0.82	0.65	0.77	0.60
<i>Characteristic temperatures, °C, of:</i>				
Melting (t_1)	1556	1523	1541	1511
Liquidus	987	1038	1007	1050
Littleton ($t_{6.65}$)	739	731	742	734
Annealing (t_{12})	551	568	555	570
<i>Working indexes</i>				
Realities machine speed, %	103.6	110.5	105.6	112.4
Forming interval, °C	198	174	197	173
Crystallization index	38	14	37	13
Drop temperature, °C	1227	1190	1220	1053

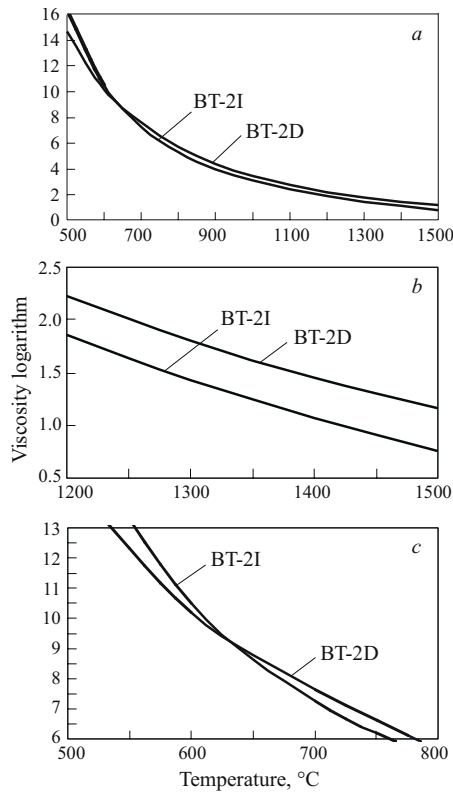


Fig. 2. Temperature dependence of viscosity of glass BT-2 at the stage of glass melting (*a*), preparation for forming (*b*), and fixing product shape (*c*).

The dependences $\log \eta = f(t)$ shown in Fig. 2*a* discriminate the intervals corresponding to the process of glass melting, machine feeding ($10 - 10^2$ Pa · sec), and fixing the product shape ($10^{6.65} - 10^{12.3}$ Pa · sec).

Viscosity logarithm values in the high-temperature range for the lime composition are 0.3 – 0.4 units lower than for the dolomite composition. Considering the significant dependence of the rate of glass formation and clarification rate viscosity, one can say that having passed to the lime composition of glass, the glass-melting process becomes more intense:

$$\tau = K_1 \frac{\eta^2}{t};$$

$$v = K_2 \frac{R^2(\rho_{gl} - \rho_{gas})}{\eta},$$

where τ is the glass formation duration; K_1 and K_2 are constants; v is the gas bubble rise velocity; R is the gas bubble radius; ρ_{gl} and ρ_{gas} are the densities of glass and gas, respectively.

This technological advantage of lime compositions should be used either by lowering the melting temperature

with a constant glass melt output or by increasing the specific melt output while maintaining a constant melting temperature. In both cases the specific energy consumption (per product unit) decreases and production efficiency grows.

The effect of the main glass composition on the solidification rate depends on the effect of individual oxides on glass viscosity [3]. Obviously (Fig. 2*c*) the viscosity of lime glass within the shape-fixing interval grows faster, consequently, the estimated relative speed of the glass-forming machine is 112.4%, which is 7% higher than with dolomite glass. This advantage of the lime composition should be used in production by means of increasing efficiency (the number of cuts) of the glass-forming machine. It is logical to assume, that the facts discussed above concerning the substantial difference in the machine performance at different companies and the existing lag behind the declared machine parameters is related to using inappropriate glass compositions.

Consequently, using compositions rich in calcium oxide should be considered as a reserve for raising the efficiency of production, in particular, using the following directions:

- decreasing melting temperature (up to 50°C) with a constant glass melt output will save fuel and improve the operating parameters of the furnace;
- keeping a constant melting temperature makes it possible to increase the specific glass melt output (up to 15%) due to intensifying the glass-melting process as a result of a decreasing glass melt viscosity;
- orientation to high specific output up to 3000 kg/(m² · day) in designing glass-melting furnaces will help to decrease the furnace dimensions and, accordingly, improve the technical and economic production parameters;
- decreasing the drop temperature will improve the performance of the feeders and the systems for droplet feed and distribution;
- increasing the efficiency of glass-forming machines with a simultaneous decrease in the weight of the product will raise the line efficiency and decrease the material consumption.

Furthermore, lime glass compositions have higher chemical resistance and, accordingly, comply with the principle of proportionality, i.e., ensuring an optimal balance between the working and service characteristics, which is a topical principle [3].

According to economical calculations, the production cost of a bottle of capacity 500 ml made from the lime glass composition making use of its technological advantages, can be brought lower by 15 – 17%. Using lime-dolomite compositions containing up to 10.0 – 11.0% CaO and 1.5 – 2.5% MgO, the positive effect is substantial as well.

The performed calculations and experiments agree with conclusions of the authors in [4 – 6] and once more convincingly demonstrate the advisability of using high-calcium glass compositions by domestic glass container manufacturers.

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